Wheel Power Loss: Rolling On Edge

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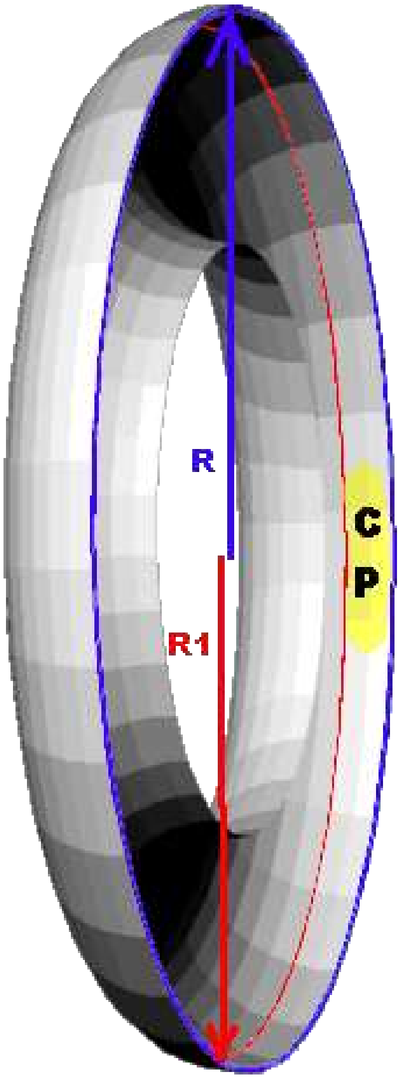
Introduction

Some time ago I looked at the Rolling Power Loss of an inline wheel rolling normally through a modest deformation at the tire's contact patch. This led to heating and the power loss was estimated. However, as soon as the wheel is turned onto its edge other effects enter. These lead to additional power loss and probably to wheel wear.

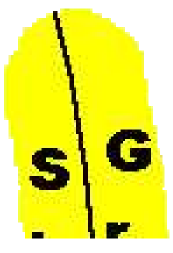
Here I will be looking at a highly simplified model of rolling on edge which will give an estimate of the edge power loss which is closely related to rolling resistance.

The Model

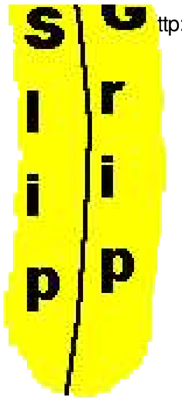


The image on the right shows half of an inline tire represented as a torus or inner tube. We are looking down from above toward the ground. The wheel is leaned slightly to the left and the blue circle is located at the exact center of the wheel. If it is an 80mm wheel the major radius R is R=40mm. The contact patch is labelled "CP" and the wheel's radius (red circle) on the left edge of the contact patch is R1 which might be about 39mm.

Since the wheel's radius is decreasing to the left this is like trying to roll a cone forward. It works fine if you let the cone turn to the left but if you try to roll it straight ahead there is clearly a problem. Part of the cone has to slide. Returning to the real wheel, the circumference at the wheel's center (right edge of the contact patch here) is C = 2*PI*R while the circumference at the left edge of the contact patch is C1 = 2*PI*R1. For the example I gave earlier then C = 251.3mm and C1 = 245.0 mm. So the right edge of the contact patch moves about 6mm farther per revolution than the left edge of the contact patch. So it would seem that if the right edge of the contact patch is fully gripping as it rolls then the left edge of the contact patch has to slide 6mm per revolution.



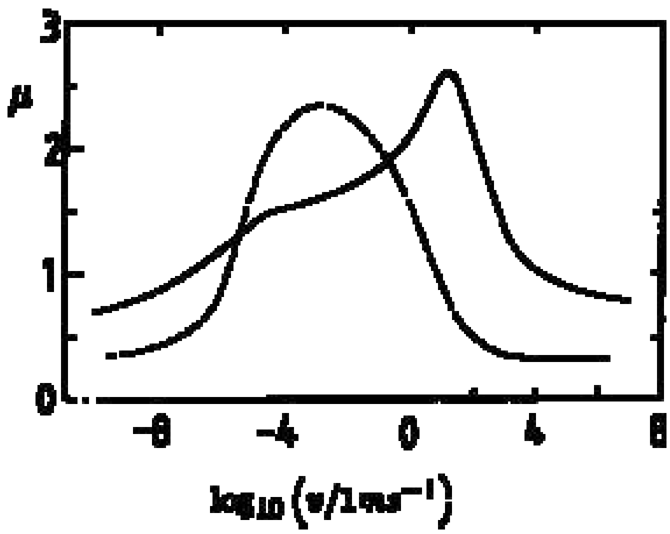
Now the contact patch alone is shown on the left. If the right hand side of the patch is gripping then the velocity there is zero with respect to the ground. However, the left



side, which slips, moves relative to the ground at a speed *vslip* of 6mm per revolution period. Now the revolution period depends on the skater's speed (velocity at the axle of the wheel). So the revolution period decreases the faster the skater moves. Consequently the slip speed *vslip* is zero when the skater is at rest and increases to 0.25 meters/sec when the skater moves at high speed (10 meters/sec).

The power lost in rolling on edge will include the friction power: Pf = Ffvslip*, where for example *vslip*=0.125m/s for a skater moving forward at 5m/s for the example used here. And the frictional force Ff = Mu*M*g. I take half the skater's mass (the other half is assumed to be rolling, not sliding) which might be 50kg and use g=9.8m/s^2 for the acceleration of gravity.**

Lastly, we need an estimate for the sliding coefficient of friction of the wheel. The friction results for rubber are shown on the right plotted vs. the logarithm of the slip velocity. One curve is for rubber on glass and the other is for rubber on fine sandpaper. The rubber data is from the Juelich site. Urethane data seems hard to find. Contrary to the claims of elementary textbooks the sliding friction coefficient at times is not smaller than the static coefficient, does depend on sliding speed, and can exceed one.



I will take a fairly small value for the sliding coefficient of friction -- say Mu=0.25 . Now the edge power loss can be estimated and it turns out to be 15.6 Watts for the speed of 5m/s. At 10m/s the loss would be 31.2 Watts. The example here had a contact patch whose width reached to R1=49mm (D1=78mm, D=80mm). This wheel was probably too soft . If the wheel diameter at the left edge of the contact patch had been 79mm the 5m/s power loss would have been only half as large - 7.8 watts. (Assuming Mu is the same). Nevertheless, it illustrates the need for a narrow width contact patch which seems attainable only with harder wheels. Actually, the power loss is probably dominated by Mu rather than by the contact patch width. The softer wheel will stick to the ground stronger (adhesion) giving a larger coefficient of sliding friction.

Discussion and Conclusions

A simplistic model of edge rolling resistance was presented. It seems that the slip when rolling on edge not only heats the wheel -- it also grinds away the outer edge of the tire through sliding friction. The need for wheels as hard as will grip seems apparent in order to minimize the edge power loss. This edge loss is largest when rolling straight ahead. So long as the wheel is allowed to turn at its natural radius the slip disappears. Once the surface of the wheel has worn to a flat or inverted

"V" shape the contact patch can become much wider with far greater power loss.

The normal Rolling Resistance which heats the wheel as the contact patch area is deformed still occurs when rolling on edge. So it looks like the slip loss from rolling on the edge should be added to the normal rolling power loss. This would make the edge power loss about double the normal rolling power loss for the cases looked at here. More data is needed for real wheels before the models can become more accurate.

Click to go back to the *INDEX*
